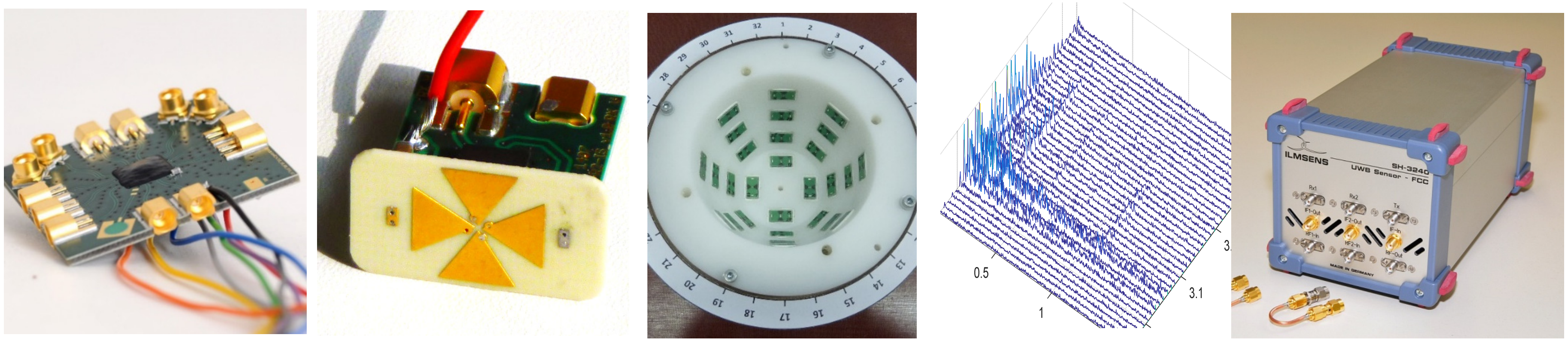
ILMSENS
UWB Sensor
SH-3240
FCC
0.5
1
3.1
3

# Short Interfacial Antennas for Medical Microwave Imaging

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Ilmsens GmbH

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# Abstract

Practical as well as theoretical aspects of medical microwave imaging require short antennas with short impulse response function for transmission and reception of the sounding fields. Since usually antenna design goals are targeted to good feed point matching, one runs into unsolvable problems in case of wideband measurements. The paper will introduce a radar channel model based on electrically short antennas and it will discuss how to circumvent the mismatch problems.

***Keywords***—*microwave imaging; short dipole; large current radiator; active directional bridge; radar channel*

# Biography

**Jürgen Sachs** is Senior Lecturer at Ilmenau University of Technology, Germany. He teaches "Electrical Measurement Technology", "Measurements in Communications", and "Ultra-Wideband Radar Sensing". He is head of several research projects, and inter alia coordinator of European projects for humanitarian demining and disaster relief. He is member of the executive committee of the ICUWB conference and TPC-member of various conferences in microwaves and radar. His research areas cover RF-signal analysis and RF-system identification; Surface Penetrating Radar for non-destructive testing and medical engineering, Ultra wideband (UWB) methods and their application in high resolution radar and impedance spectroscopy, digital processing of UWB-signals, UWB-Array processing; and design and implementation of new RF device approaches. He is author or co-editor respectively of the books “Handbook of Ultra-Wideband Short-Range Sensing” and “Ultra-Wideband Radio Technologies for Communications, Localization and Sensor Applications”.

# Outline

- Motivation for short antennas in medical microwave imaging
- Transmission between short antennas
- Active feeding
- Application examples

# Motivation

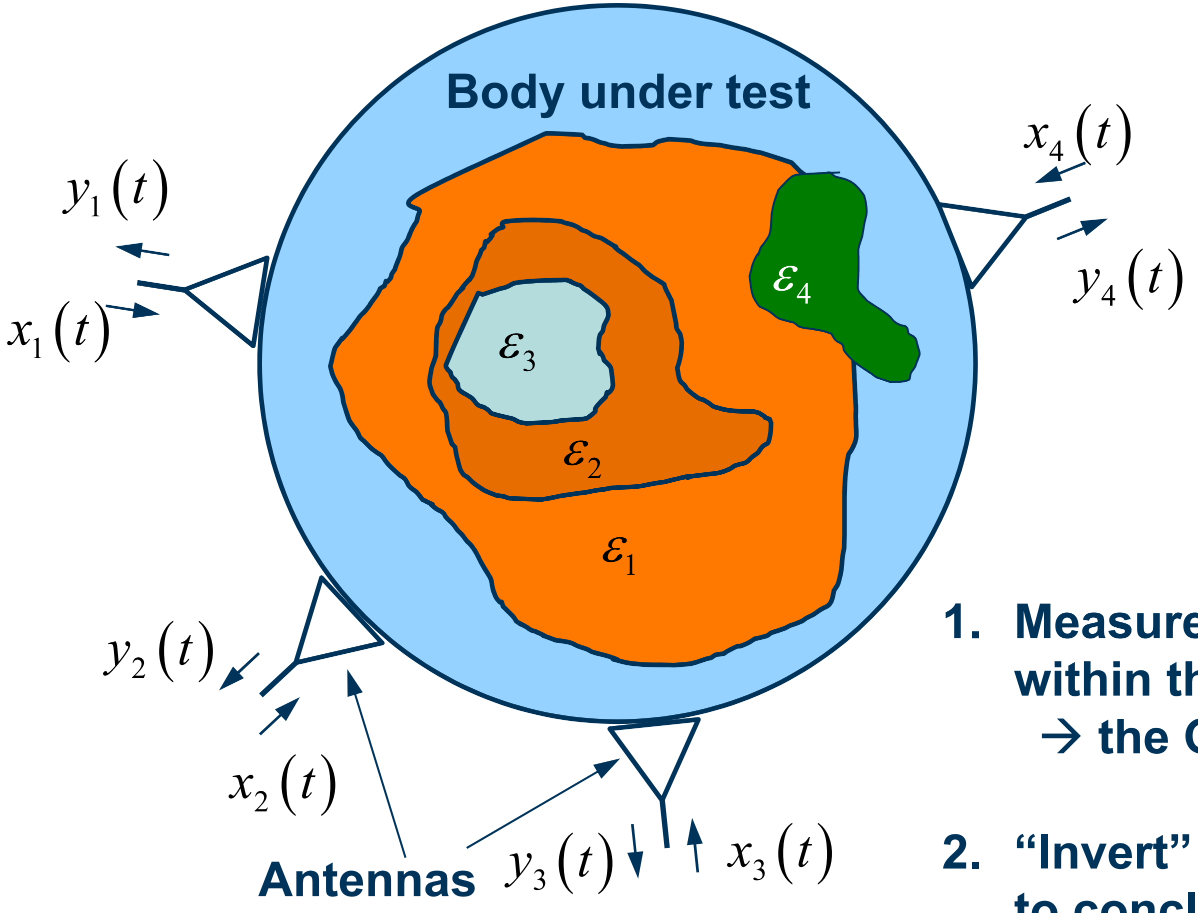
## Contact non-invasive based medical microwave sounding (Body Penetrating Radar)

- Imaging
- Vital motion detection and localization
- Contrast agent detection and localization

## Consequences

- Operation at low frequencies – tissue penetration
- Operation at large bandwidth – spatial resolution
  - → fractional bandwidth > 100%
  - → Operational band 1… 5 GHz
- Operation over short distances (cm … dm)
- Small Antenna array

# Generic Imaging Set-up


Body under test
$\varepsilon_1$
$\varepsilon_2$
$\varepsilon_3$
$\varepsilon_4$
$y_1(t)$
$x_1(t)$
$y_2(t)$
$x_2(t)$
$y_3(t)$
$x_3(t)$
$x_4(t)$
$y_4(t)$
Antennas

1. **Measure the wave propagation within the body under test**
   **→ the Green's function**
   $$G(\mathbf{r}_j, \mathbf{r}_i, t)$$
2. **"Invert" the Green's functions to conclude the material distribution**

# Green’s Function

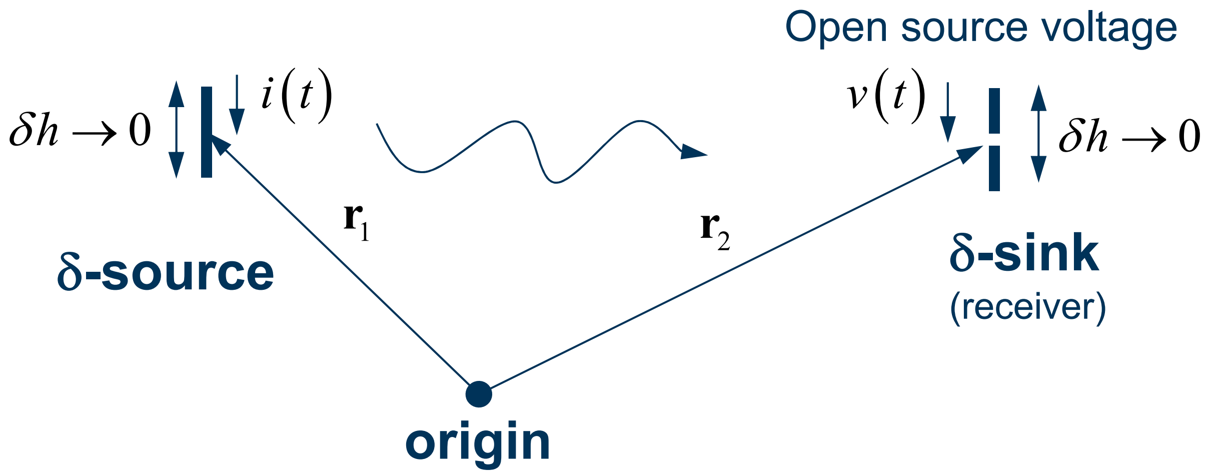
**Illustratively, it represents the impulse response function of the transmission from a delta current source at position $\mathbf{r}_1$ to a delta voltage sink at position $\mathbf{r}_2$ .**

$$v(t)\big|_{\mathbf{r}=\mathbf{r}_2} = G(\mathbf{r}_2,\mathbf{r}_1,t)\cdot I_0\delta(t,\mathbf{r}-\mathbf{r}_1)$$

**Short pulse excitation**

$$v(t)\big|_{\mathbf{r}=\mathbf{r}_2} = \left(G(\mathbf{r}_2,\mathbf{r}_1,t)*i(t)\right)\cdot\delta(\mathbf{r}-\mathbf{r}_1)$$

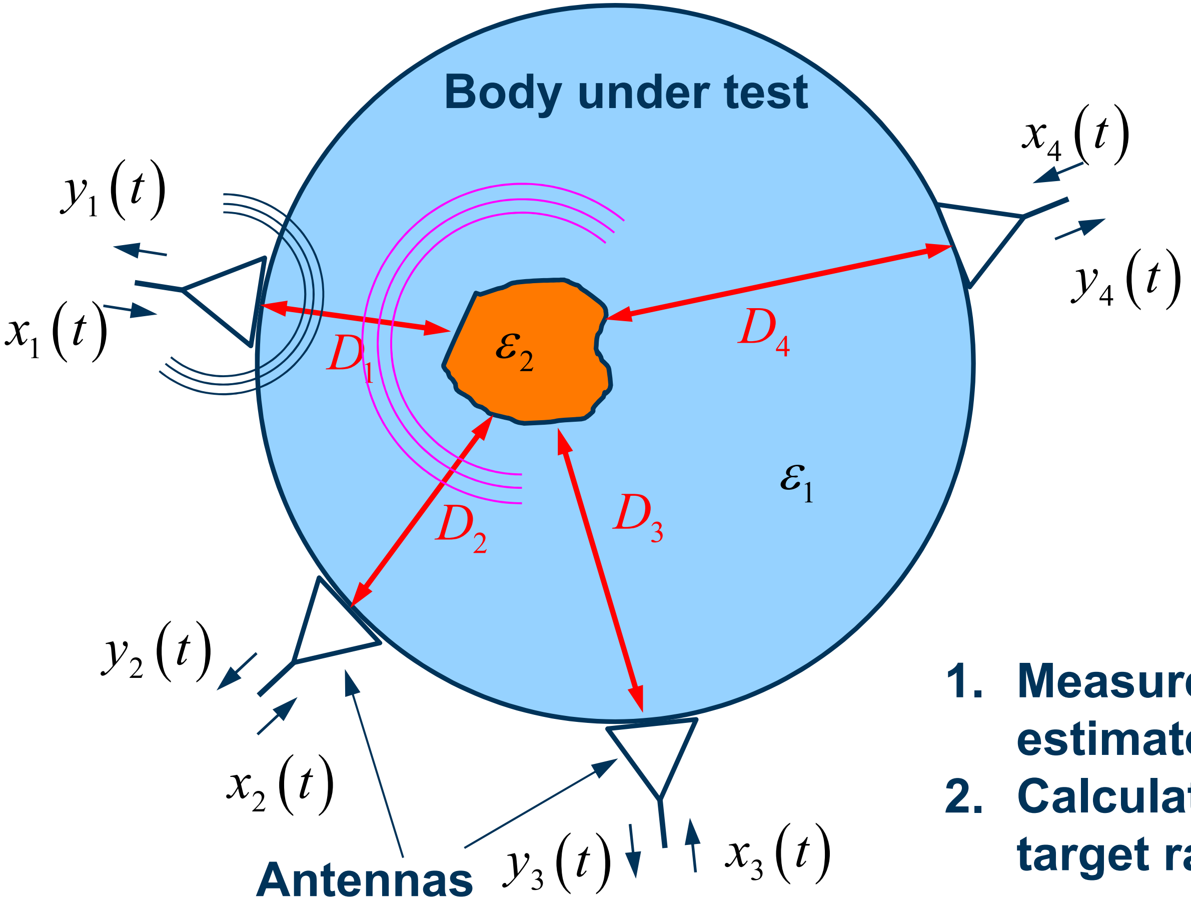
**Arbitrary wideband signal**


Open source voltage
$v(t)$
$\delta h \to 0$
$i(t)$
$\delta h \to 0$
$\mathbf{r}_1$
$\mathbf{r}_2$
δ-source
δ-sink
(receiver)
origin

# Green's Function

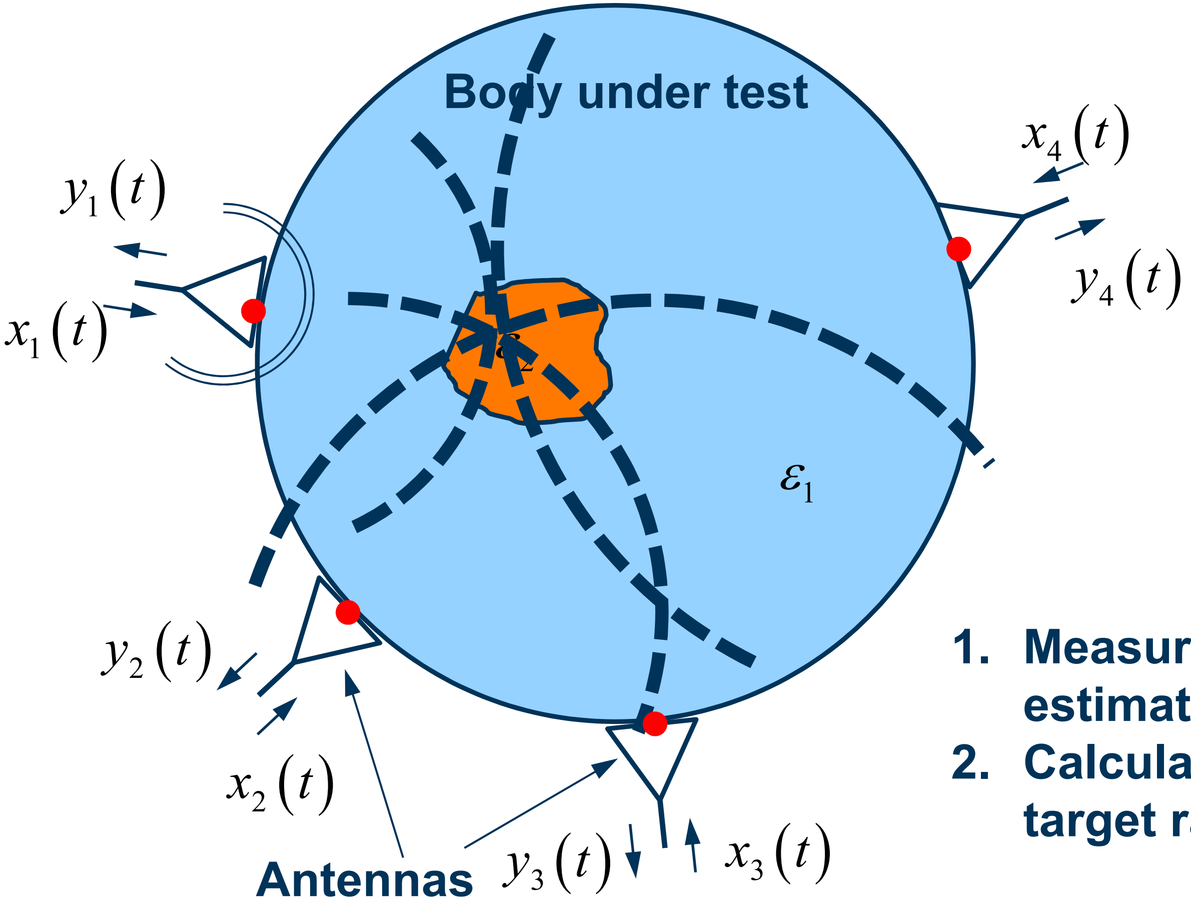
**Short antennas are needed since they best approximate infinitesimal radiators as required by Green's approach.**

# Localization


Body under test
$y_1(t)$
$x_1(t)$
$y_2(t)$
$x_2(t)$
$y_3(t)$
$x_3(t)$
$x_4(t)$
$y_4(t)$
$D_1$
$D_2$
$D_3$
$D_4$
$\varepsilon_2$
$\varepsilon_1$
Antennas

1. **Measure roundtrip time and estimate target range**
2. **Calculate intersection of all target ranges**

# Localization


Body under test
$y_1(t)$
$x_1(t)$
$x_4(t)$
$y_4(t)$
$\varepsilon_2$
$\varepsilon_1$
$y_2(t)$
$x_2(t)$
Antennas
$y_3(t)$
$x_3(t)$

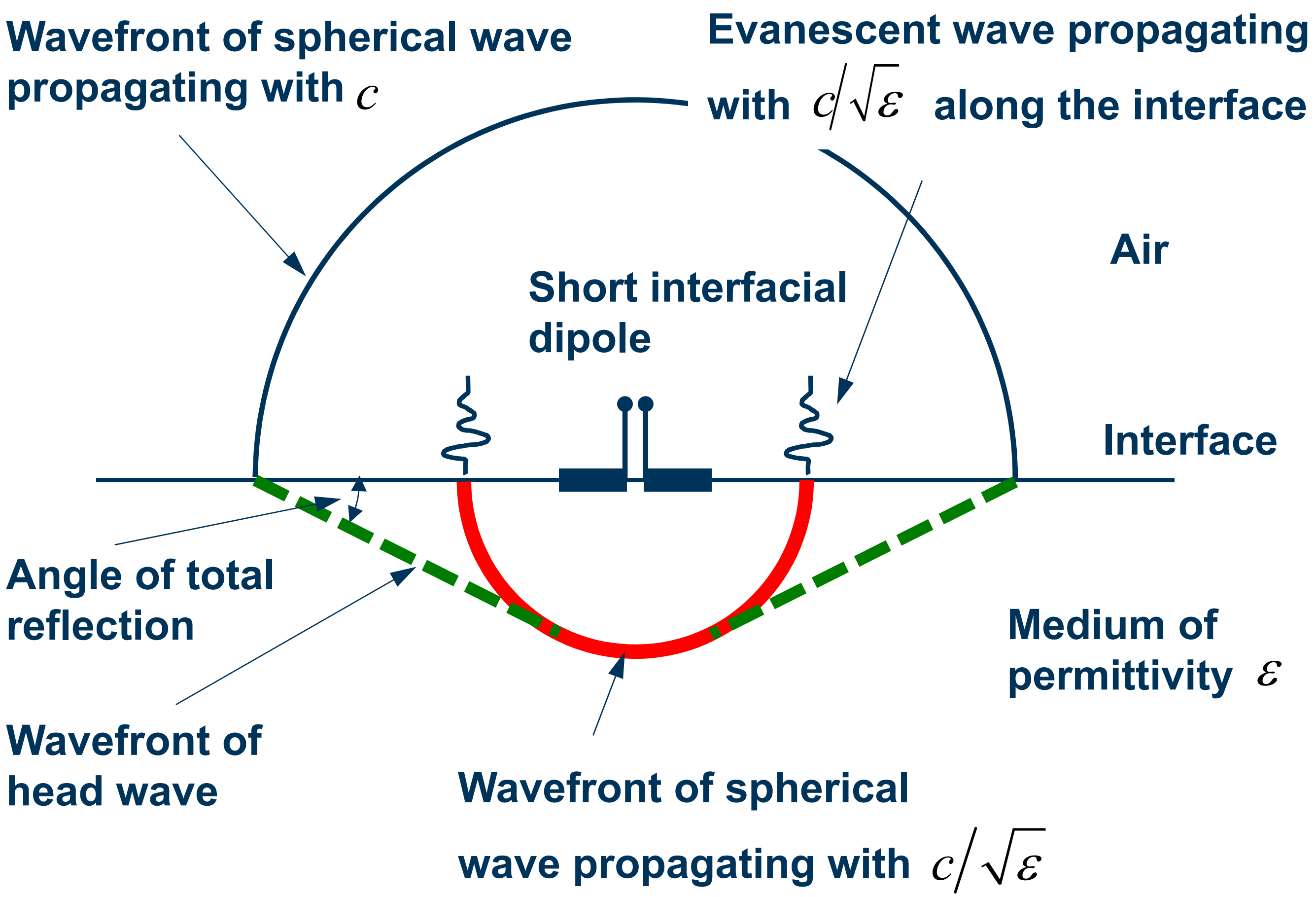
1. **Measure roundtrip time and estimate target range**
2. **Calculate intersection of all target ranges**

# Localization

**Short antennas needed**

- **since they have a well defined radiation center**
- **Since they provide a spherical wavefront (homogenous propagation medium supposed)**

# Interfacial Antenna



**Wavefront of spherical wave propagating with $c$**

**Evanescent wave propagating with $c/\sqrt{\varepsilon}$ along the interface**

**Air**

**Short interfacial dipole**

**Interface**

**Angle of total reflection**

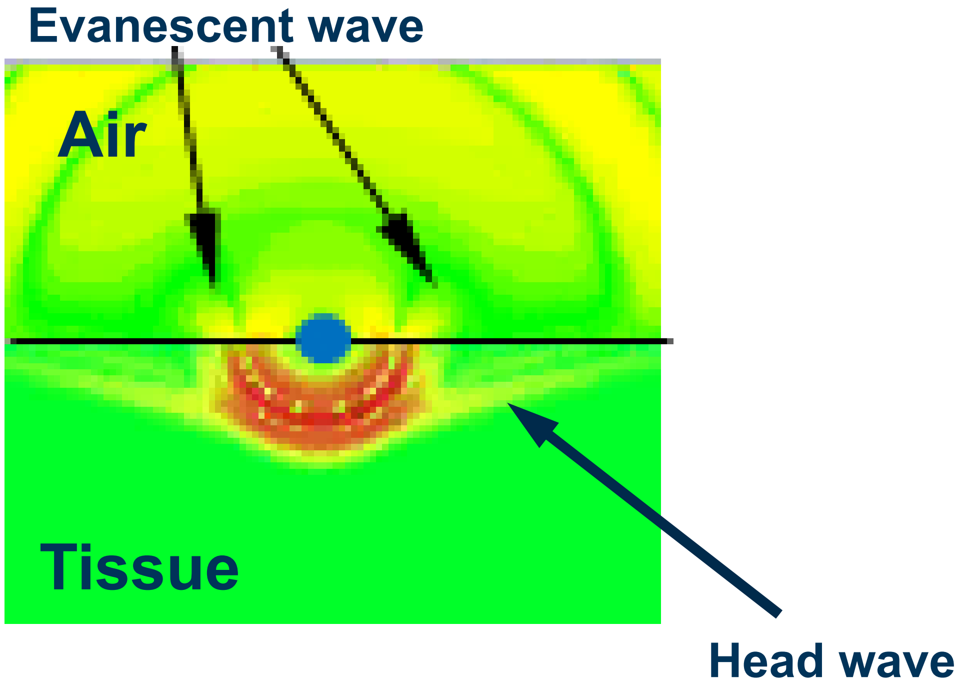
**Medium of permittivity $\varepsilon$**

**Wavefront of head wave**

**Wavefront of spherical wave propagating with $c/\sqrt{\varepsilon}$**

# Interfacial Antenna

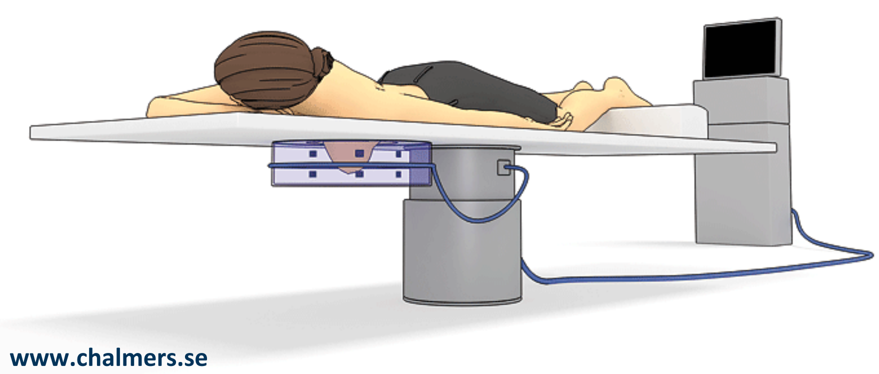
## Waves of a short interfacial dipole


Evanescent wave
Air
Tissue
Head wave

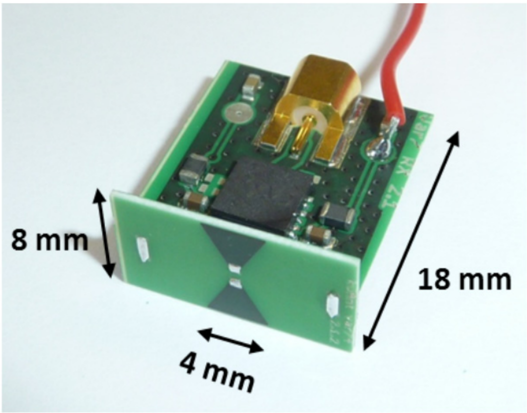
# Interfacial Antenna

**From all antennas which operate close to a boundary, the short antenna provides the simplest wavefront pattern.**

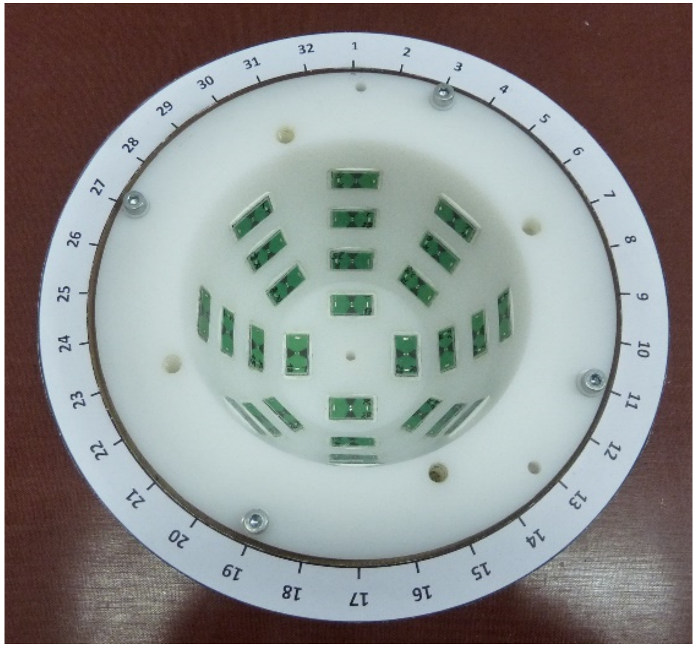
# Limited Array Dimensions

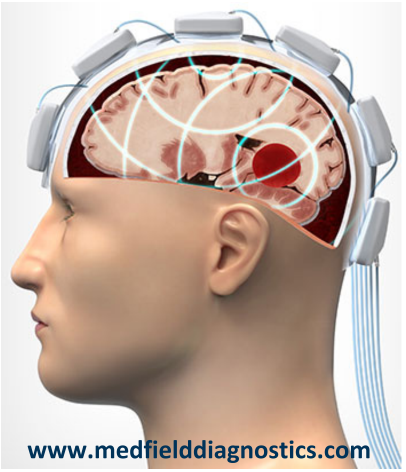


www.chalmers.se


8 mm
18 mm
4 mm

Breast mold with antenna array


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32



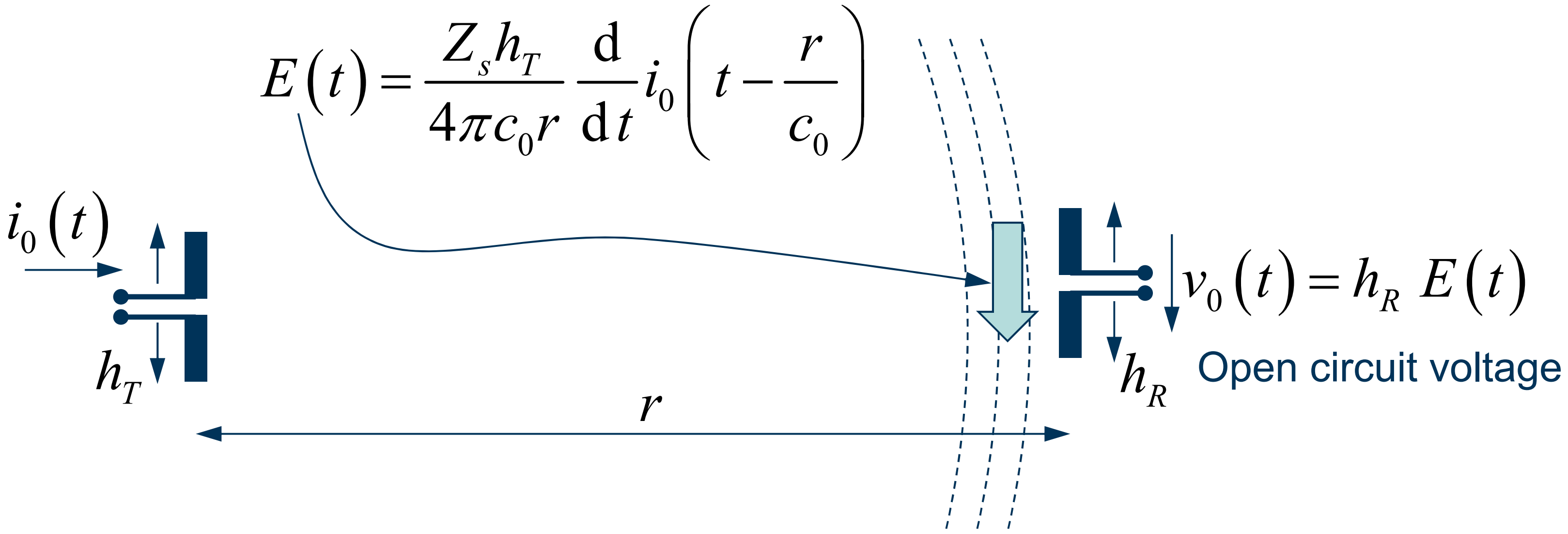
www.medfielddiagnostics.com

# Limited Array Dimensions

**Antenna arrays which are restricted by their geometric size can only be populated with small antennas.**

# Dipole – Dipole Transmission

$c_0$ Speed of light
$Z_s$ Intrinsic impedance

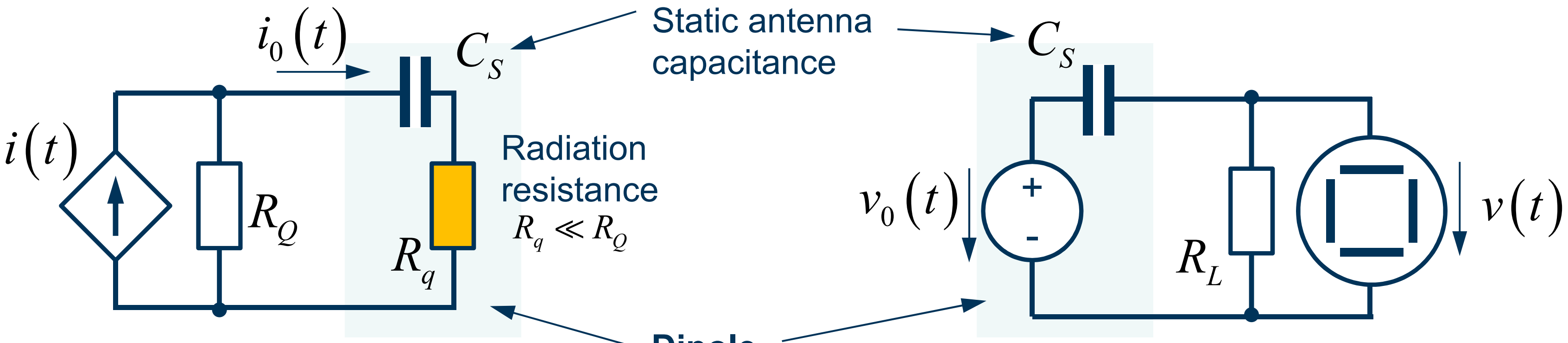


$$E(t)=\frac{Z_s h_T}{4\pi c_0 r}\frac{\mathrm{d}}{\mathrm{d}t} i_0\left(t-\frac{r}{c_0}\right)$$

$v_0(t)=h_R\,E(t)$

Open circuit voltage

## Equivalent feeding circuit



Static antenna capacitance

Radiation resistance $R_q \ll R_Q$

**Dipole**

**Transmitter**

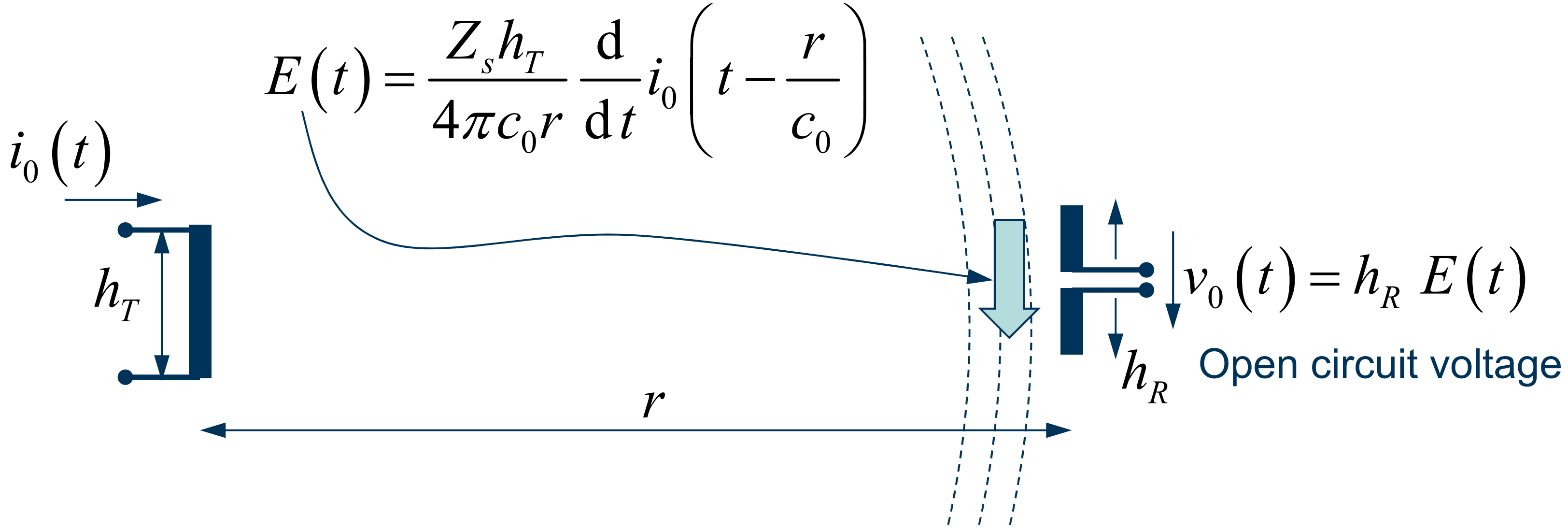
**Receiver**

# Dipole – Dipole Transmission

- Low frequency components of the radiated field are important due to their good penetration into biological tissue.
- By physics, the transmission of an electric field leads to a differentiation. This suppresses the important low frequency components of the sounding field.
- The feeding circuits for receive and transmit mode provide additional differentiation, which should be avoided by selecting high-ohmic internal source or load impedance.

# LCR –Dipole Transmission

$c_0$ Speed of light
$Z_s$ Intrinsic impedance

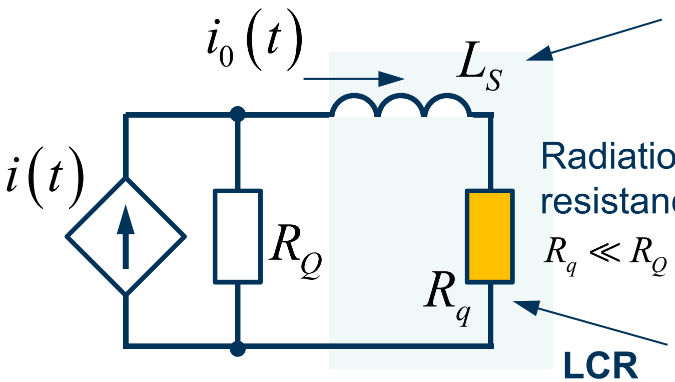


$$E(t) = \frac{Z_s h_T}{4\pi c_0 r} \frac{\mathrm{d}}{\mathrm{d}t} i_0\left(t - \frac{r}{c_0}\right)$$

$$v_0(t) = h_R\ E(t)$$

Open circuit voltage

## Equivalent feeding circuit



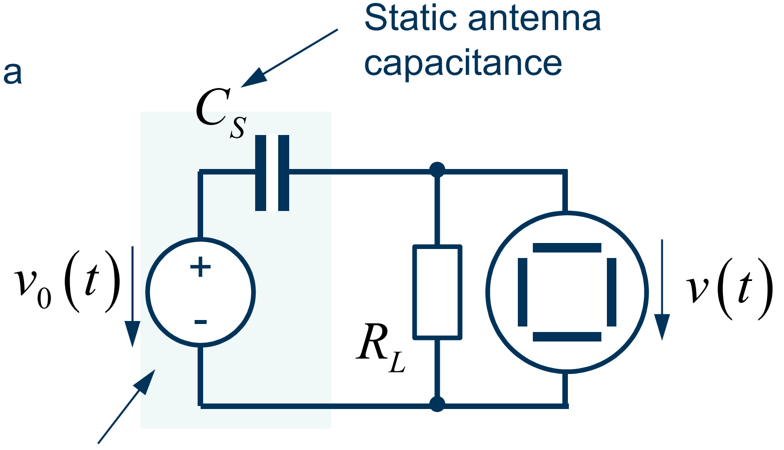
Static antenna inductance

Radiation resistance

$R_q \ll R_Q$

**Transmitter**

**LCR (large current radiator)**



Static antenna capacitance

**Dipole**

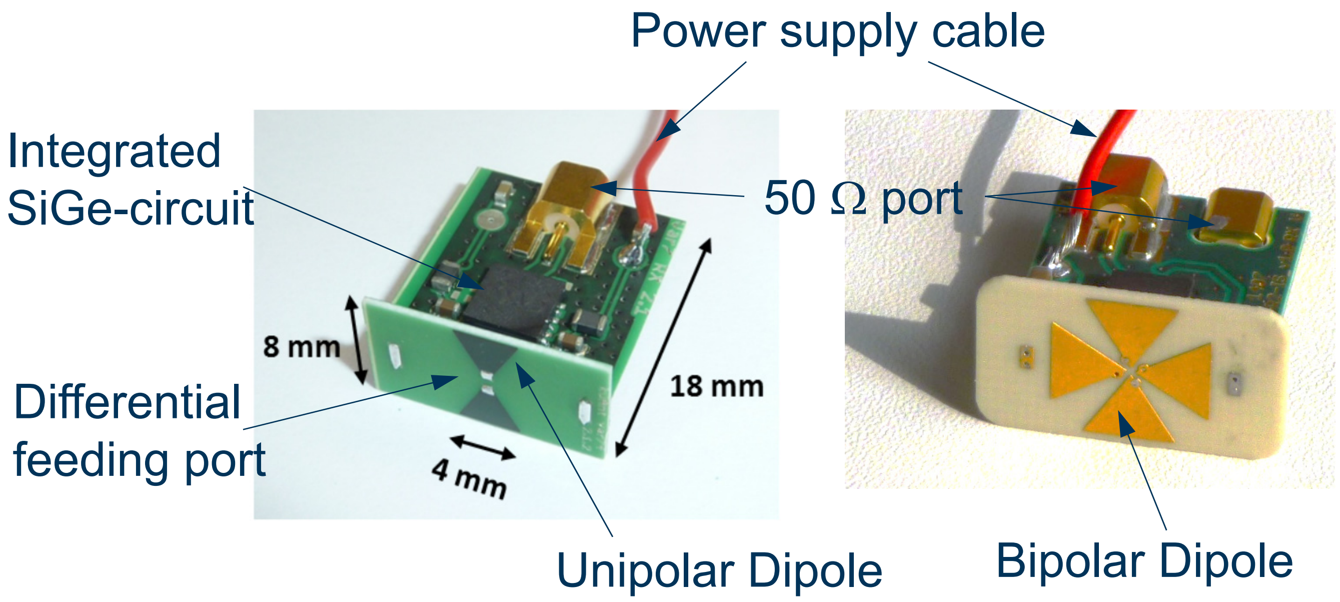
**Receiver**

# LCR –Dipole Transmission

**The LCR feeding circuit leads to an integration by selecting an appropriate internal source impedance. Hence, the differential behavior of the electric field generation may be partially compensated.**

# Active Feeding – Unidirectional Antennas

- **Avoid feeding cables to bypass cable matching**
- **Transmitter amplifier:**
  - **Single-ended to differential amplifier**
  - **50 Ω input matching**
- **Receiver amplifier:**
  - **differential to single-ended amplifier**
  - **50 Ω output matching**

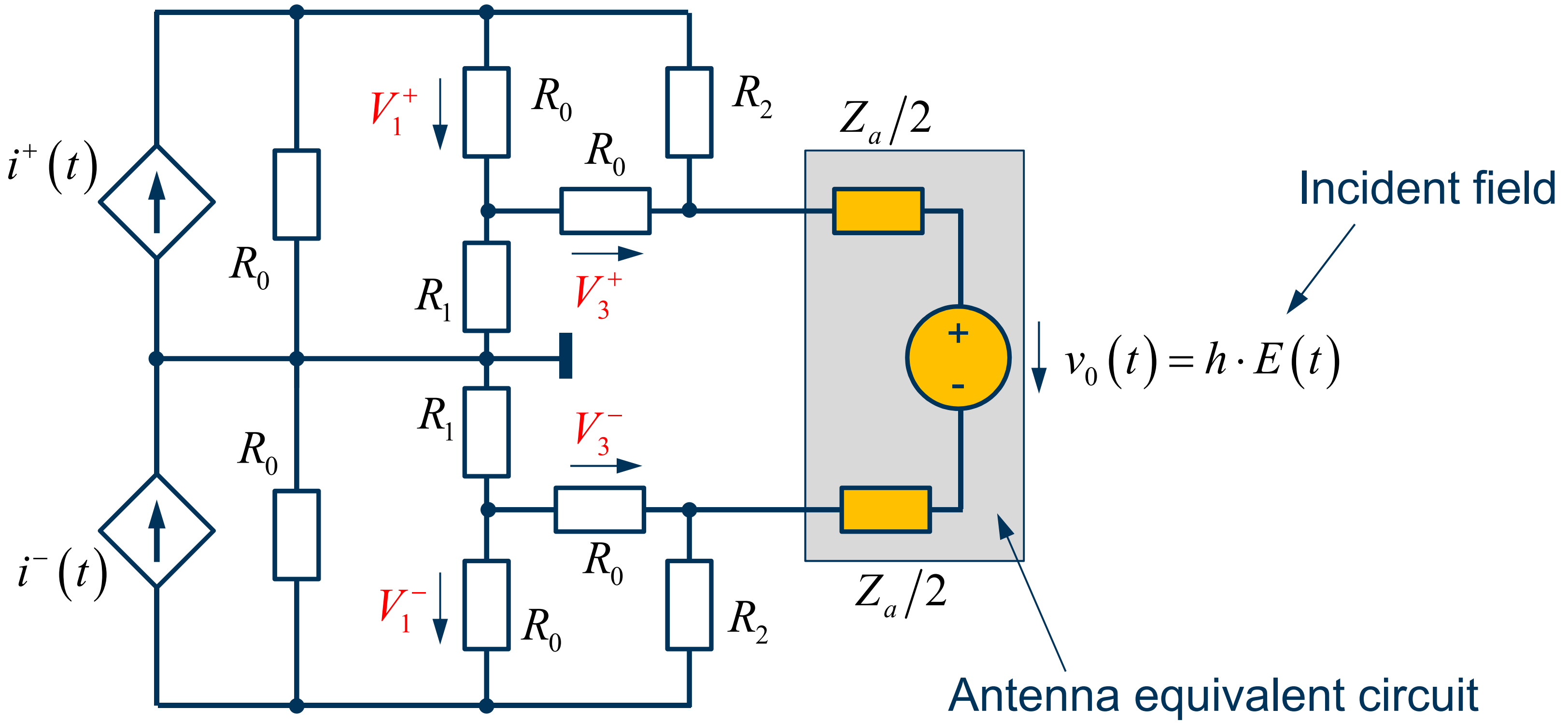

Power supply cable
Integrated SiGe-circuit
50 Ω port
8 mm
18 mm
Differential feeding port
4 mm
Unipolar Dipole
Bipolar Dipole

# Active Feeding – Bidirectional Antenna

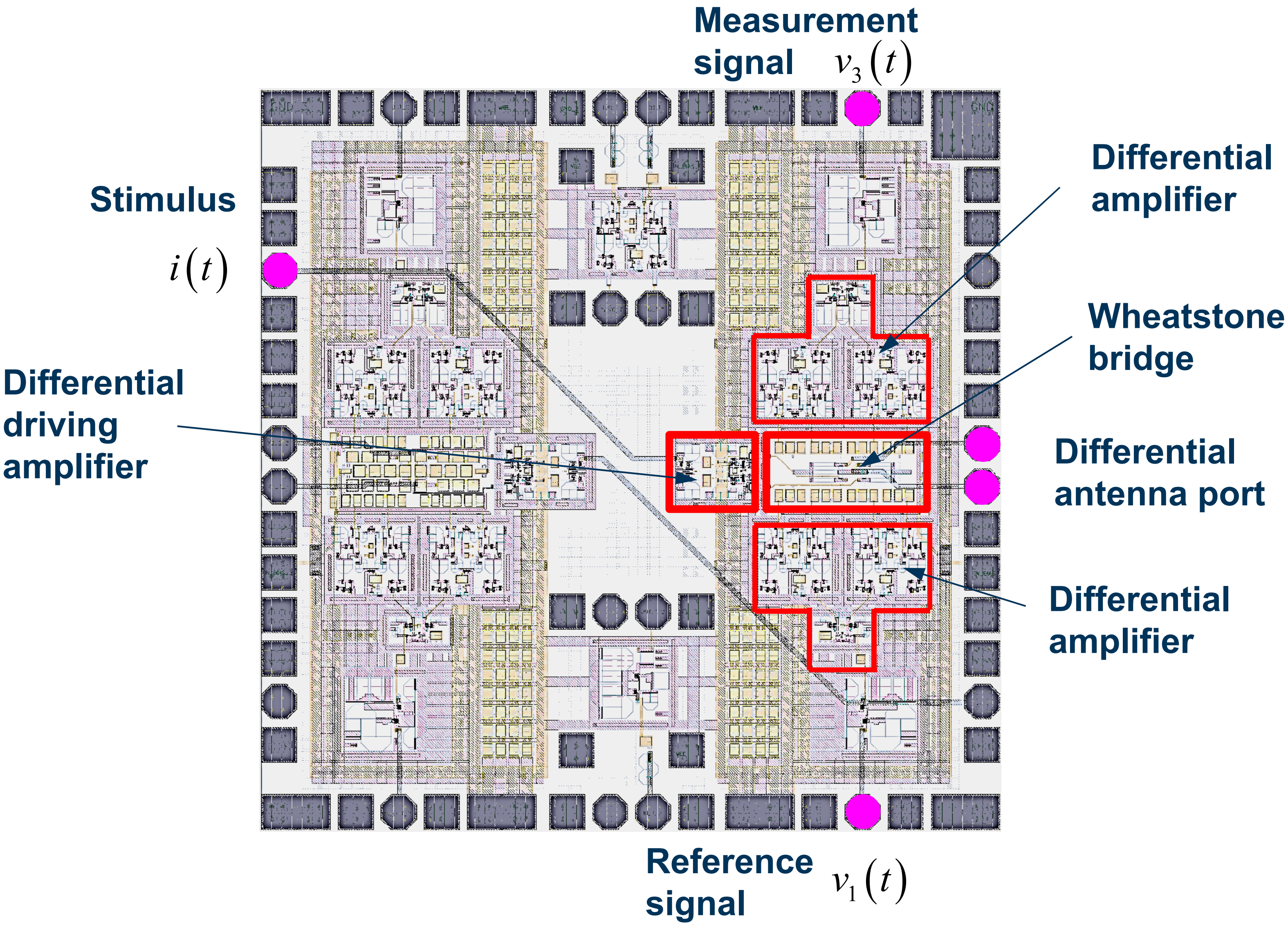
## Differential Wheatstone-Bridge → no lower cut-off frequency

Case 1: $i^{\pm}(t) = 0$ Pure receiver mode $V_3^{\pm} \sim v_0(t)$

Case 2: $i^{\pm}(t) \neq 0$ Mono-static radar $V_3^{\pm} \sim v_0(t)$ and $Z_a \cdot V_1^{\pm}$


$i^+(t)$
$i^-(t)$
$R_0$
$R_0$
$V_1^+$
$R_0$
$R_2$
$R_0$
$Z_a/2$
$R_1$
$V_3^+$
$R_1$
$V_3^-$
$R_0$
$V_1^-$
$R_0$
$R_2$
$Z_a/2$
+
-
$v_0(t) = h \cdot E(t)$
Incident field
Antenna equivalent circuit

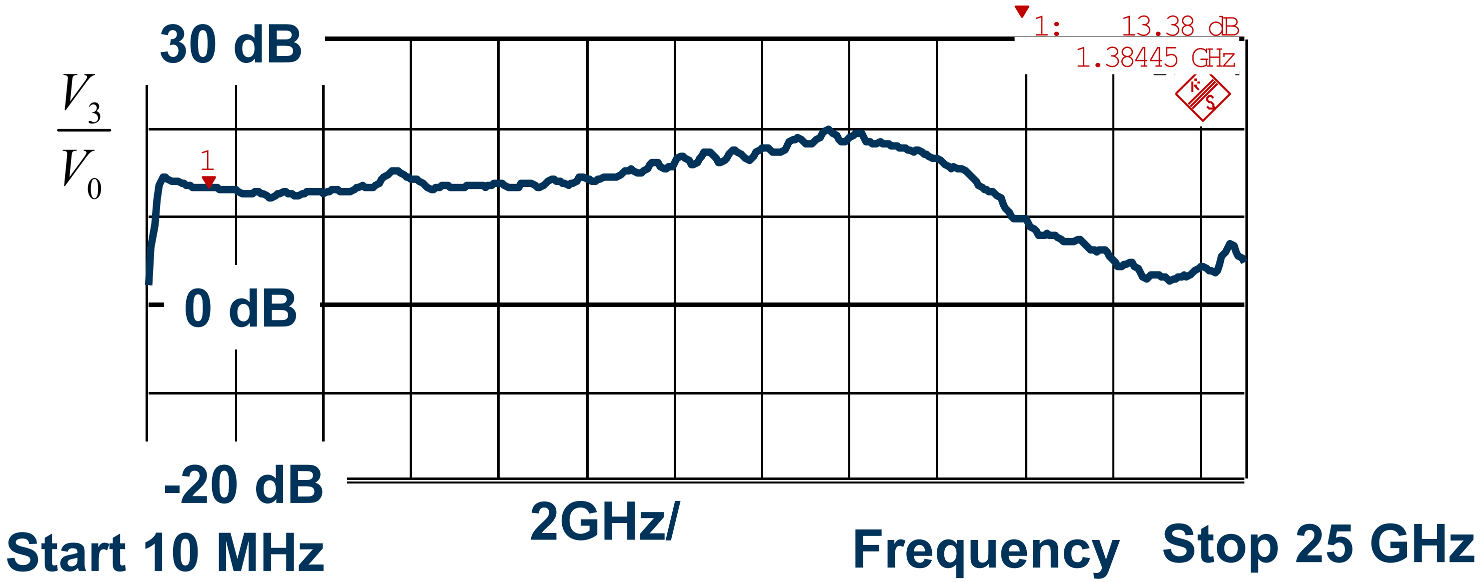
# Active Feeding – Bidirectional Antenna


Measurement signal $v_3(t)$
Stimulus $i(t)$
Differential amplifier
Wheatstone bridge
Differential driving amplifier
Differential antenna port
Differential amplifier
Reference signal $v_1(t)$

IWAT 2017 International Woprkshop on Antenna Technology; Athen March 1st-3rd

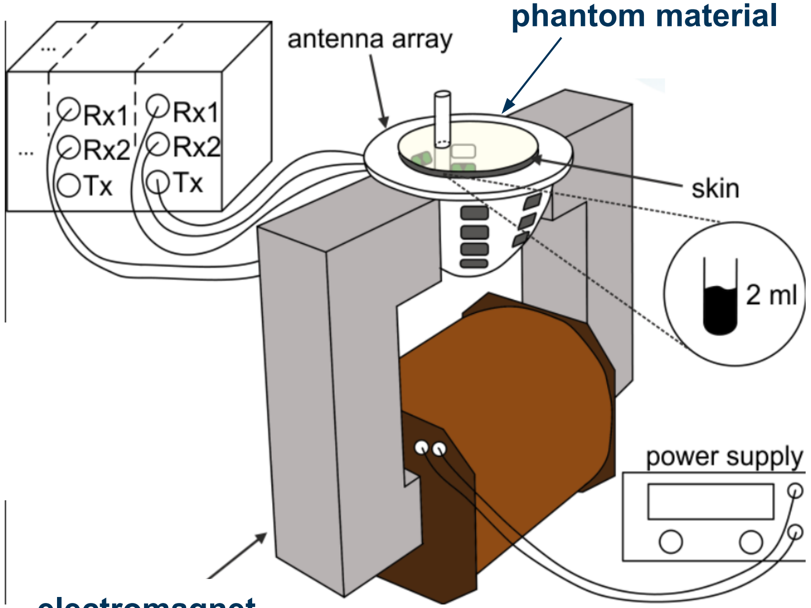
# Active Feeding – Bidirectional Antenna

## Transmission function of the bridge for the receiving mode



# Example: Modulated Nanoparticles - Imaging

## Experimental set-up

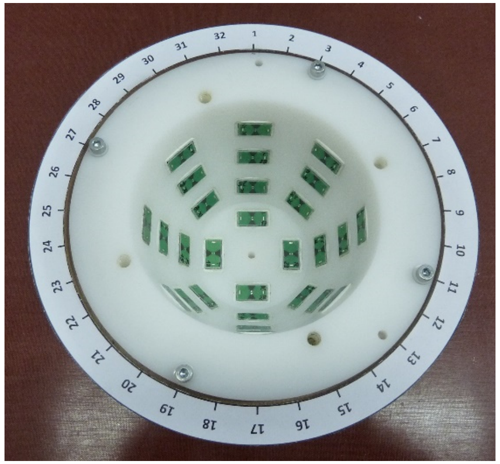

**MiMo-UWB-device**

**Breast mold with phantom material**

**electromagnet**
...
Rx1
Rx2
Tx
Rx1
Rx2
Tx
...
antenna array
skin
2 ml
power supply

S. Ley; M. Helbig; J. Sachs: Contrast enhanced UWB microwave breast cancer detection by magnetic nanoparticles. EUCAP 2016

**Breast mold with antenna array**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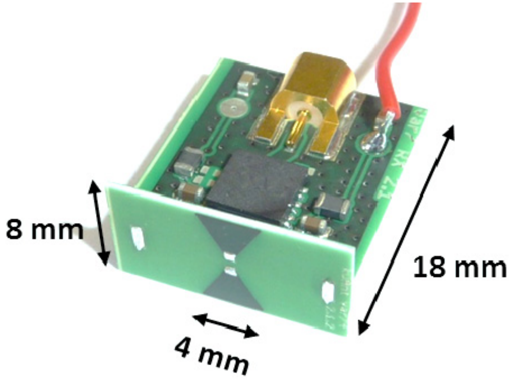
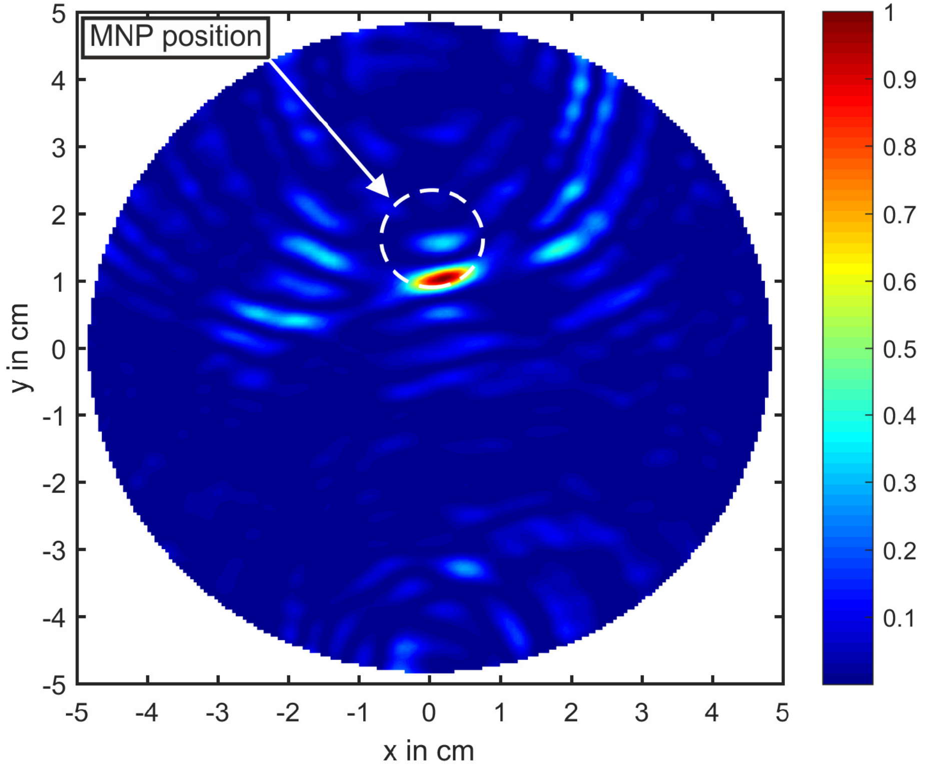
**Short, active interfacial dipoles**


8 mm
18 mm
4 mm

# Example: Modulated Nanoparticles - Imaging

## Differential image

based on “delay and sum” approach



S. Ley; M. Helbig; J. Sachs: Contrast enhanced UWB microwave breast cancer detection by magnetic nanoparticles. EUCAP 2016

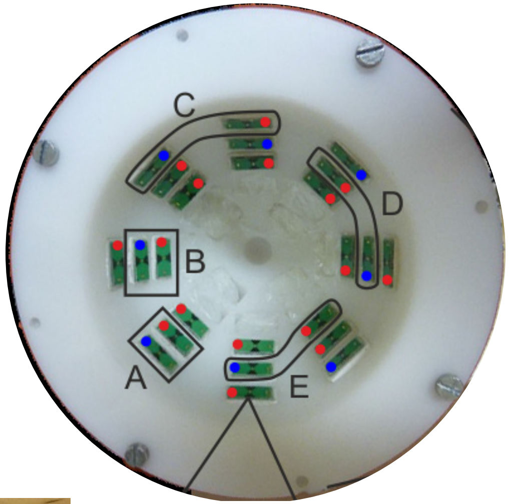
# Example: Intrinsic Patient Motion

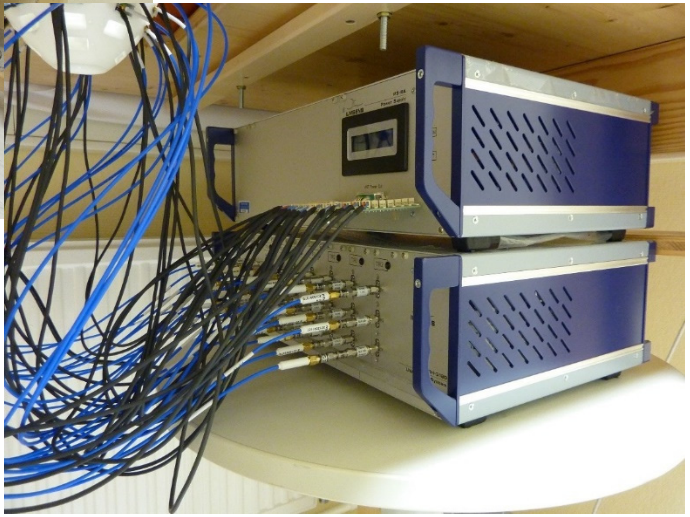
- **Healthy volunteer**
- **Assessment of intrinsic micro motion of a female breast**

**Breast mold**

Patient examination table with breast mold

Breast mold with active antennas



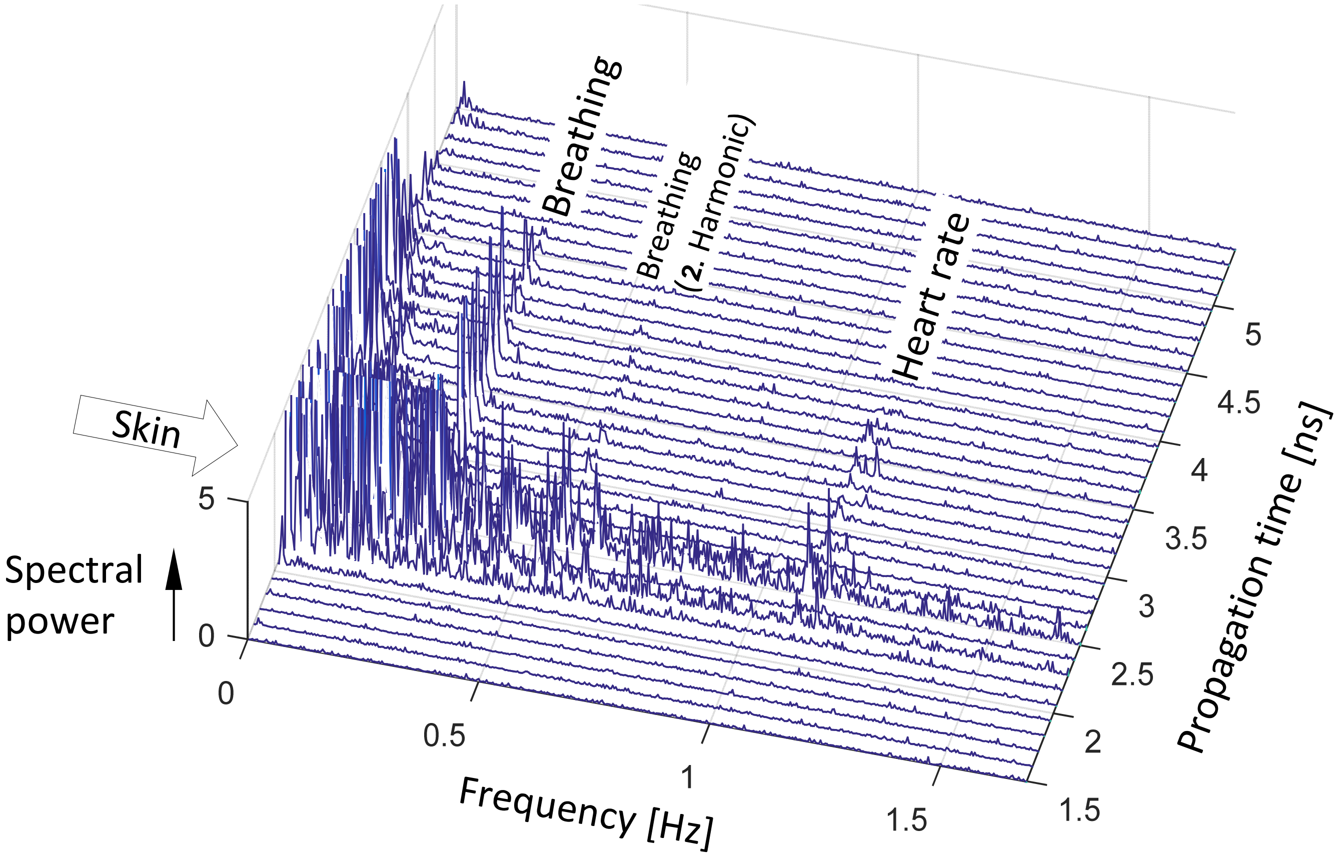


8Tx/16Rx – MiMo radar

# Example: Intrinsic Patient Motion

## Time variance of antenna coupling

- **Left breast**
- **Volunteer remains motionless but was breathing**



# Summary

## Short antennas

- provide well defined wavefront.
- are well suited for imaging purpose under nearfield condition.
- operate over a large bandwidth if they are appropriately fed.
- require active feeding in order to avoid
  - multiple reflections at feeding cables
  - additional differentiations by the feeding circuit.

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